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# A Performance Comparison of Mobile WiMAX Spectrums: 2.5 GHz vs. 3.65 GHz

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**Abstract**—Mobile WiMAX is a popular broadband solution with diverse applications. In the United States, the Federal Communications Commission (FCC) currently issues licenses for Mobile WiMAX in several frequency bands, of which 2.5 GHz and 3.65 GHz are the most prevalent. A significant amount of research has been conducted in the domain of 2.5 GHz due to its widespread commercial use. However, no such work – academic or industrial – has been reported for 3.65 GHz, in spite of it being a more favorable option for many applications, particularly because of its licensing requirements. In this paper, we present a comprehensive comparison of these two frequency bands in order to provide benchmark results for use by network planners, engineers and researchers. Our analysis indicates that, while 2.5 GHz Mobile WiMAX generally offers a larger coverage area, the attractive licensing options for 3.65 GHz may present an interesting alternative for many deployment scenarios and applications.

**Keywords**—Mobile WiMAX; 2.5 GHz; 3.65 GHz; Comparison; Throughput; CINR; Coverage; License Requirements

## I. INTRODUCTION

Mobile WiMAX [1] has emerged as one of the most popular last mile solutions in broadband networking. Since being introduced in 2005, the protocol has gone through several advancements and now is an attractive choice for realizing ITU's worldwide 4G standardization goals.

Mobile WiMAX has been given a lot of attention by the research community. It provides high data rate and large coverage with features like QoS, handover, HARQ and vehicular mobility support, making it a cost-effective and reliable solution for a wide range of applications. Our research team at the University of Nebraska-Lincoln's Advanced Telecommunications Engineering Laboratory has been studying design, implementation and simulation of difference aspects of Mobile WiMAX [2-7] with the primary objective of designing broadband solutions for the North American railroad industry. Mobile WiMAX is a good prospective standard to deliver mobile video streaming [8, 9], VOIP [10] and broadcasting services [11]. In [12], the authors explore the prospect of using Mobile WiMAX as a broadband solution for wireless tactical broadband networks for the Finnish Defense Forces. In [13, 14], the authors present some field and laboratory test results of WiMAX equipment in different environments. However, their results have limited scope and are intended to obtain specific objectives which cannot be generalized to draw any conclusions about generic performance of the Mobile WiMAX standard under different operating conditions. Nonetheless, all these research endeavors enhance

the importance of Mobile WiMAX as an important research area.

The Federal Communications Commission (FCC) issues licenses for Mobile WiMAX operators in various bands for the U.S., among which 2.5 GHz and 3.65 GHz are the most popular ones. Most of the work done in the community has been centered on 2.5 GHz operation. The primary reason behind this is that the higher operating frequency of 3.65 GHz undergoes significant propagation losses. This makes the spectrum unfavorable to some broadband operators that require very large coverage for a widespread customer base since they will have to install more base stations to serve the same area when using a higher frequency. Furthermore, operations in 3.65 GHz are EIRP transmit power restricted.

However, the favorable licensing requirements for 3.65 GHz spectrum [15, 16] make it an economically prospective solution for deployments with more focused and restricted coverage requirements, such as localized consumers, or industrial operation monitoring and control.

With the current focus on 2.5GHz deployments, there are only very few research publications reported that focus on studying 3.65GHz characteristics. Some work [17-19] has been reported on performance and implementation of 3.5 GHz Mobile WiMAX but the band is not available for commercial use in the United States.

In this paper, we present a detailed quantitative analysis of the performance of the two spectrums under different operating conditions. The results presented in this paper serve three purposes: 1) They provide an overview comparison of the two spectrums to allow network planners, engineers, and researchers to select the most appropriate spectrum for their requirements. 2) The presented results are applicable for link budget and performance modeling. 3) Our results can also serve as benchmark for future testing and product evaluation.

The rest of the paper is divided into the following sections. Section II will explain the methodology used for testing. Section III will discuss the experiments performed. We present our results and their discussion in Section IV. Finally, section V will conclude our paper.

## II. METHODOLOGY

In this section we describe the equipment we utilized, channel conditions implemented and network topology used throughout our testing.

### A. Equipment

#### 1) Mobile WiMAX Devices

In our tests we utilized commercial off-the-shelf (COTS) equipment to evaluate the performance of 2.5GHz and 3.65 GHz spectrums.

For testing 2.5 GHz, we used RuggedCom’s RuggedMax WiN7000 [20] and RuggedMax WiN5100 vehicular subscriber unit [21] as the base station (BS) and the subscriber station (SS), respectively. Both devices are IEEE 802.16e-2005 and WiMAX Forum Wave2 Profile compliant. Each of them has two transceiver antennas, thus enabling a 2x2 MIMO configuration.

For 3.65 GHz testing, we used PureWave Network’s Quantum 1000 [22] as the BS and Gemtek’s ODU-series CPE [23] as the SS. They are IEEE 802.16e-2005 and WiMAX Forum Wave2 Profile compliant devices as well. The BS uses a four element antenna array, two for transmitting and all four for receiving. The SS has two transceiver antennas, thus allowing a 4x2 MIMO configuration.

### 2) Channel Emulator

Azimuth Systems’ ACE 400WB [24] wireless channel emulator was used to create the test conditions between the communicating Mobile WiMAX devices. It provides sophisticated software-controlled emulation of user-defined real-world physical channels with great accuracy. Testing the equipment by using a channel emulator rather than over-the-air transmissions provides significant advantages:

The channel emulator provides total control of the testing environment. A wireless channel is random and dynamic, as well as easily and severely affected even by small changes in the test conditions (like temperature, humidity, moving vehicles and people), most of which are beyond our control.

Also, because over-the-air channel parameters are highly dynamic, it is impossible to recreate the channel and replicate testing for any sort of comparison. Since we cannot control individual channel parameters, there is no way to isolate their effect in order to determine their performance impact.

However, by using a channel emulator, we have complete and individual control over all channel conditions. We can gradually vary the desired parameters and study their effect one at a time in a controlled, reliable, and repeatable environment.



Figure 1. RuggedMax WiN7000 2.5GHz and Purewave Quantum 1000 3.65GHz Base Stations



Figure 2. Azimuth System's ACE 400WB Channel Emulator

### B. Network Topology

The network diagram used throughout our tests is shown in Figure 3.

For our 2.5 GHz tests, the BS and the SS were connected to ports A and B of the channel emulator, which creates a virtual user-defined wireless channel between them. Each of the devices was connected to a laptop via RJ45 Ethernet cable for

data transfer and device management. The BS-side laptop was designated as the server while the SS-side computer was designated as the mobile end user or customer. Both laptops were configured as data generator or receiver, depending on the test requirements and traffic direction, to send and receive UDP packets. They also accessed the web-interfaces for device management and Telnet sessions to extract relevant statistics from the devices. The management traffic was isolated from the test data traffic. The channel emulator was configured in a 2x2 MIMO configuration.

For 3.65 GHz testing, the topology was similar except for the BS having all four antenna ports connected to the channel emulator and thus enabling a 4x2 MIMO configuration.

The various device and link parameters under which the equipment was tested are shown in Table 1.

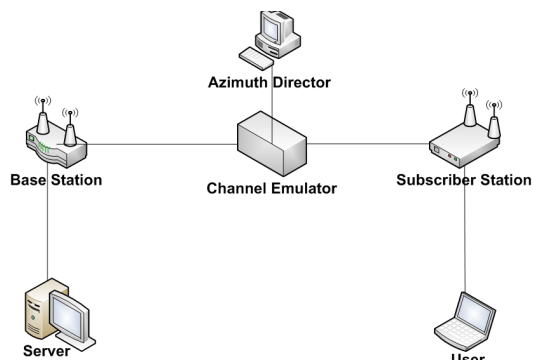


Figure 3. Network Topology for Equipment Testing

Table 1: Channel/Device parameters for performance measurement

Channel/Link Parameter	Values	
	2.5 GHz Test	3.65 GHz Test
Central Frequency	2.5 GHz	3.65 GHz
Bandwidth	10 MHz	
Frame Duration	5 ms	
Downlink/Uplink Ratio	35/12	
Uplink Channel Descriptor (UCD) Interval	1000 ms	
Downlink Channel Descriptor (DCD) Interval	1000 ms	
CBR traffic rate (DL)	25 Mbps	
CBR Packet Size	1400 bytes	
BS Transmit Power	23 dBm	
SS Transmit Power	27 dBm (max)	24 dBm (max)
Channel Path Loss	85-135 dB	80-135 dB
ARQ	OFF	
HARQ	OFF	
Power Control	ON	
Adaptive Modulation and Coding	ON	
Antenna Configuration	2x2 MIMO-A	4x2 MIMO-A

### III. PERFORMANCE EVALUATION DESCRIPTION

In this section, we describe the various channel configurations and test conditions utilized for testing.

#### A. Channel Models

Though the channel emulator is capable of creating any user-defined channel, in this paper we have limited our work to standard ITU channel models – Butler, Pedestrian A and B and Vehicular A and B. We measured the device performance parameters by emulating the SS speed of 0 km/hr, 2.5 km/hr

and 5 km/hr for the pedestrian models and 0 km/hr, 30 km/hr, 60 km/hr and 90 km/hr for the vehicular models. For Butler model, only 0 km/hr was used.

### B. Observed Performance Indicators

#### 1) Throughput

The performance of a Mobile WiMAX device is primarily indicated by its effective end-to-end throughput. It is the most important parameter that is impacted by the quality of the link. In terms of network planning, it provides insight into the number of users a single base station will be able to serve in a given area.

#### 2) Coverage

For a network service provider the supported coverage area which a base station can reliably serve is also important. It directly determines the maximum possible distance of the user from the serving base station. Coverage area has to be taken into consideration in order to determine the number of serving base stations necessary to provide reliable service for a desired area. This also has an effect on effective handover during future operations.

#### 3) CINR (Carrier to Interference+Noise Ratio)

Evaluating the CINR information is imperative for comparing the two spectrums. A higher Received Signal Strength Indication (RSSI) expresses a higher transmit power or lower path loss, but does not take into account the noise and interference present in the channel or at the receiver. A higher CINR, on the other hand, is more directly related to better

received signal conditions and hence higher throughput.

Since different vendors may implement certain aspects of Mobile WiMAX using proprietary techniques, we may not be able to observe the same throughput-coverage relationship for all equipment, mainly due to the difference in hardware and signal sensitivity. Therefore, to draw a conclusion on performance of the two spectrums based only on throughput and coverage will be insufficient. RSSI is a good measure of the received signal strength independent of any particular device. However, since RSSI does not account for noise and interference in the channel, a higher RSSI does not always mean higher throughput [2]. Therefore, CINR is needed to study the effects of the channel and the receiver on link performance. A lower CINR directly indicates a lower effective throughput, even at high RSSI and closer distance from the serving base station.

After setting up the described test configuration our tests were conducted by gradually increasing the path loss between the communicating devices. This was accomplished through changing the software-controlled attenuator in the channel emulator. At each attenuation step we then observed the desired parameter values.

Also, we converted the path loss as measured by the channel emulator to effective separation between BS and SS using the Friis equation.

$$Path\ Loss = 10n \log_{10} \left( \frac{4\pi d}{\lambda} \right) \quad (1)$$

where  $d$  is the separation between BS and SS,  $\lambda$  is the

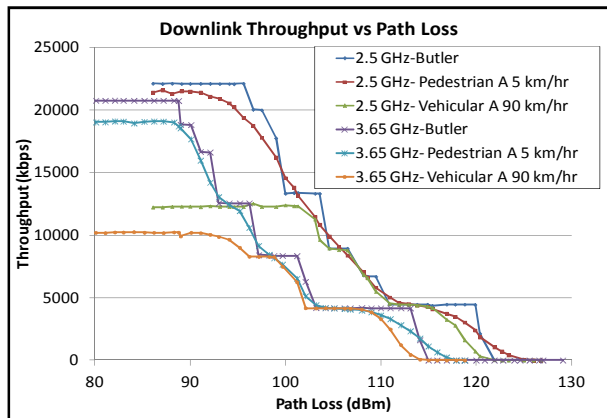


Figure 4: End-to-End DL throughput vs. Path Loss

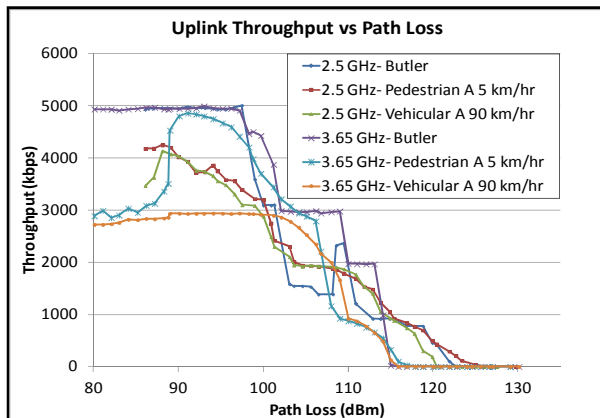


Figure 5: End-to-End UL throughput vs. Path Loss

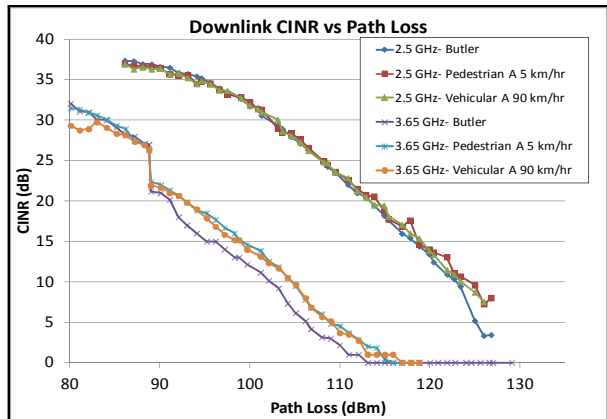


Figure 6: Change in downlink CINR with path loss

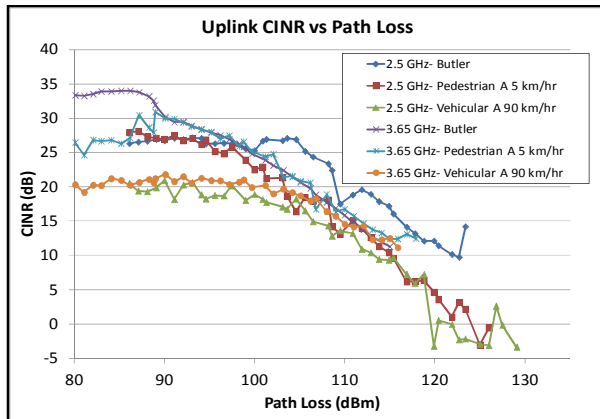


Figure 7: Change in uplink CINR with path loss

wavelength of the carrier wave and  $n$  is the path loss exponent.

#### IV. RESULTS AND ANALYSIS

Some of our test results are presented in figures 4-10. Due to size limitations and for clarity we have refrained from presenting all the results in this paper

Figures 4 and 5 show the effect of increasing the path loss between BS and SS on the end-to-end effective uplink and downlink throughput for different channel conditions. As expected the throughput decreases with an increase in distance or path loss. We can also see that, while the downlink throughput curve is monotonic, the uplink curve is not. This is a result of SS transmit power control. The BS directs to the SS to increase transmit power to maintain a constant uplink RSSI when the path loss is increased. Due to this increase in transmit power, the CINR often improves and thus results in a sudden increase in effective uplink throughput.

One observation from the throughput curves is the maximum path loss before link failure. Our results show that the 2.5 GHz equipment works up to a path loss of 125 dBm while the 3.65 GHz devices work only up to 115 dBm.

Figures 6 and 7 show the downlink and uplink CINR for the corresponding unidirectional data transmission. The downlink CINR values for 2.5 GHz equipment are noticeably better than those for 3.65 GHz for the same BS transmit power of 23 dBm and same channel conditions. This advantage of the 2.5GHz results can be attributed primarily to vendor-specific implementations of hardware and firmware. This clear separation in CINR accounts for much of the path loss improvement shown by the 2.5 GHz equipment over the 3.65 GHz devices. The higher effective downlink throughput curves of 2.5 GHz can similarly be attributed to this higher CINR.

Figures 8 and 9 show the end-to-end throughput achieved with respect to CINR. Though the 3.65 GHz equipment seems to exhibit higher throughput for the same CINR compared to 2.5 GHz, this is entirely due to path loss. For example, at an average downlink CINR of 20 dB, using the Vehicular-A 90 km/hr model, the net downlink throughput for 2.5 GHz equipment is 5 Mbps, while it is 10 Mbps for the 3.65 GHz test. However, as shown in figure 6, the same CINR is achieved by 3.65 GHz at a path loss of 90 dBm, whereas it is

achieved at 110 dBm by 2.5 GHz. This 20 dB difference in path loss accounts for the lower throughput.

Figure 10 shows the change in effective throughput for both uplink and downlink directions with the path loss information converted to a corresponding distance. As expected, the 2.5 GHz spectrum has a higher coverage compared to 3.65 GHz. But the issue of interest here is how significant the loss in coverage is as a result of using a higher frequency spectrum, how much of the losses can be accounted for by the device implementation and can these losses be compensated for by financial benefits of using the 3.65 GHz license.

The maximum downlink throughput under the best channel conditions for both spectrums is around 22 Mbps. Therefore, assuming an average user bandwidth utilization of 0.5 Mbps, a 2.5 GHz BS may serve 40-45 users on average with satisfactory performance within a radius of 12 km under best channel conditions ( $n=2$ ). On the other hand, the 3.65 GHz BS can still serve the same number of users, but its coverage radius will only be around 3.5 km. However, as discussed earlier, we need to account for the device implementation losses as demonstrated by CINR curves.

Under same channel conditions, the coverage distance ' $d$ ' of the serving BS is related to the carrier frequency ' $f$ ' by,

$$d \propto \frac{1}{f} \quad (2)$$

This shows that the theoretical coverage radius for 3.65GHz operation, independent of any particular implementation details, should be over 8 km vs. 2.5GHz operation providing 12 km coverage radius. But because of the 10dB difference in effective receiver sensitivity for the 3.65GHz devices, this is further reduced to 3.5 km.

If we were to consider operation in suburban environments with significant multipath contributing to a path loss exponent  $n = 2.8$ , we achieve coverage radii of only 200 m and 150 m for 2.5 GHz and 3.65 GHz, respectively.

Finally, because of federal regulations, 3.65 GHz equipment are transmit power restricted and thus operate at a lower maximum power, further reducing the supported coverage distance.

#### V. CONCLUSION AND FUTURE WORK

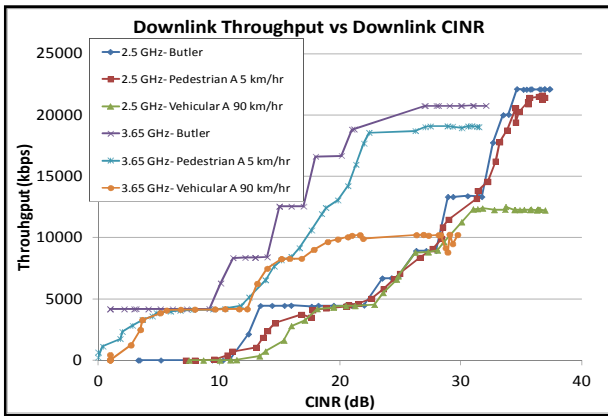


Figure 8: Variation of end-to-end downlink throughput with CINR

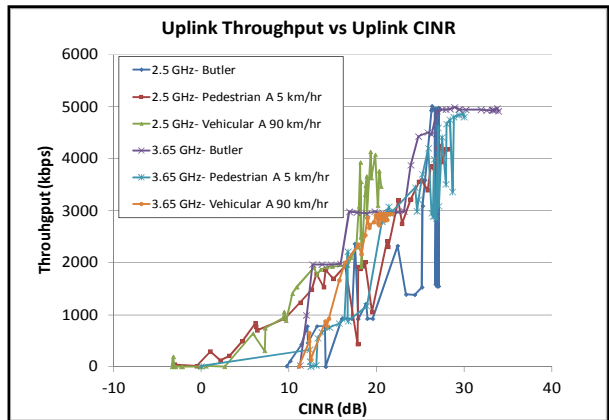


Figure 9: Variation of end-to-end uplink throughput with CINR

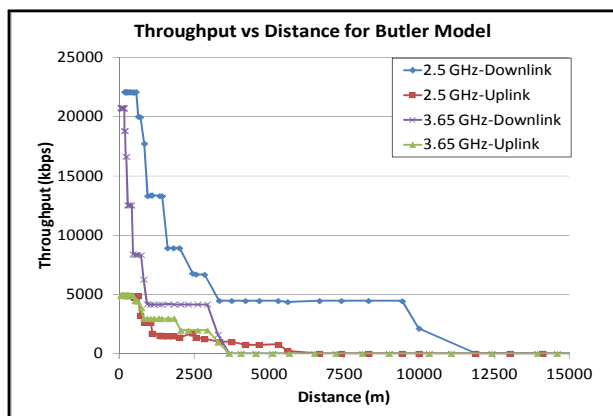


Figure 10: Comparison of uplink and downlink coverage

In this paper, we have presented concrete data comparing the performance of two common spectrums of Mobile WiMAX under a variety of operating conditions. We determined the BS coverage radius of 2.5 GHz and 3.65 GHz under best channel conditions to be 12 km and 3.5 km (8 km under device independent conditions). Though the coverage of 3.65 GHz is lower compared to 2.5 GHz, the results clearly show 2.5 GHz does not exhibit any other advantages over 3.65 GHz in terms of performance. Therefore, operation in 3.65GHz may be attractive for some deployments that only require limited coverage but for which the attractive licensing scheme of 3.65GHz is of importance. For example, in our testbeds for the North American railroad industry, implementing solutions based on 3.65 GHz spectrum is more viable economically without sacrificing communication capabilities.

Future work will include the study of commercial products from different vendors. Additionally, more performance results including Error Vector Magnitude, latency and jitter, beamforming and specific application profiles will be the focus of future publications.

## VI. ACKNOWLEDGEMENT

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